From CONT to VGOS: the Evolution of the CONT Campaigns

Cynthia C. Thomas, Dirk Behrend, Daniel S. MacMillan

Abstract Continuous VLBI campaigns (CONT) started in 1994 with the goal of demonstrating state-of-the-art VLBI over a continuous period of time. The first CONT was followed by campaigns in 1995 and 1996. After a six year hiatus, CONT campaigns were organized approximately every three years from 2002 through 2014. In this paper we primarily focus on the cornerstones of each CONT campaign. Specifically, we review the developments in networks, scheduling techniques, recording media, correlation, and other resources used. A timeline of the history of the CONTs and the goals for future campaigns will be presented. The CONTs used a significant amount of IVS resources to produce a large volume of high quality data and demonstrated the advantages of continuous observing which will soon be realized with VGOS.

Keywords Continuous VLBI, CONT, VGOS

1 Introduction

Over more than two decades continuous VLBI campaigns (CONTs) have been organized to demonstrate and exploit the capabilities of the geodetic/astrometric VLBI technique at its maximum potential at the time. The state-of-the-art of VLBI was first demonstrated over an extended continuous period of time in 1994 (CONT94). This was followed by campaigns in the two subsequent years (CONT95 and CONT96) and then, after a gap of six years, every three years starting in 2002 (CONT02, CONT05, CONT08, CONT11, and CONT14). Thus, a total of eight CONT campaigns have been observed so far.

All past eight CONT campaigns provide a snapshot of the capabilities of the legacy S/X systems in various stages of its development. As the technology advanced, analog systems were gradually replaced by digital systems. So while the early CONTs made use of thin tapes and video converters, later ones employed recording disks (Mark 5) and digital backends. Likewise the correlation went from early hardware correlators (Mark IIIA) to advanced hardware correlators (Mark IV) and eventually to software correlators (DiFX).

With the gradual implementation of the broadband VGOS system, VLBI is heading towards continuous operations by the year 2020 or shortly thereafter. Hence, once VGOS is fully established, the main characteristic of a CONT campaign—namely continuous observing—will have become the regular modus operandi of VLBI. In other words, CONT campaigns will lose their purpose by then. However, in the transitional period, CONTs may continue to be an important assessment tool of the progress of VLBI. As such, the CONT campaigns in 2017 and 2020 may be quite useful.

In the following we provide a brief history of the CONT campaigns. We address the resources used such as station and correlator time as well as recording media. We conclude with an outlook for the future CONT campaigns. The continuous VLBI campaigns can clearly be viewed as a precursor of the VGOS.

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Table 1 Overview of the history and possible future of the CONT campaigns.

Campaign	Observing period	Description
CONT94A	12–25 January 1994	13 continuous days with two independent networks running simultaneously: seven
CONT94B		non-VLBA stations (A) and seven VLBA stations (B)
CONT95	23–29 August 1995	Six continuous days
CONT96A	2 Sep. – 16 Nov. 1996	11-week campaign with non-continuous observing with ARSAC sequence the first seven
CONT96B		weeks—observed biweekly, two weeks not observing, and two parallel networks the
		last two weeks: (A) five non-VLBA stations, (B) 10 VLBA plus up to two non-VLBA stations
CONT02	16–31 October 2002	15 continuous days
CONT05	12–27 September 2005	15 continuous days
CONT08	12–27 August 2008	15 continuous days
CONT11	15–30 September 2011	15 continuous days
CONT14	6–21 May 2014	15 continuous days
CONT17	*tbd, in planning phase*	*15 continuous days on two networks (e.g., 19 legacy S/X stations and*
		seven VGOS stations)
CONT20	*tbd, under consideration*	*15 continuous days with VGOS stations*

2 History and Goals of the CONT Campaigns

Table 1 summarizes the timeline and provides a brief description of the various CONT campaigns. In the following we elaborate in more detail on the goals of the CONTs.

CONT94, CONT95, and CONT96 are three campaigns that were a prelude to the Continuous Observation of the Rotation of the Earth (CORE) VLBI project. CONT94 was a resource-intense campaign that observed two seven-station networks simultaneously: network A with non-VLBA stations and network B with VLBA stations for 13 days. CONT94A produced the lowest formal errors ever obtained using VLBI until CONT05. CONT95 was the shortest campaign. It ran for six days (August 23–29) with six participating stations. According to Clark et al., CONT95 was conducted in order to better understand the effects of higher tropospheric water vapor content and larger tropospheric delays during the Northern Hemisphere summer, which contrasts with the CONT94 winter campaign [1]. CONT96 was not observed continuously over a period of time, but it ran for 11 weeks from September 2 to November 16. CONT96 adopted an innovative observation scheme to maximize the usefulness of the data on timescales from subdaily to monthly under the correlator constraint [1]. Twenty-four observation days were selected during a period of 77 days starting September 2, 1996, according to the "ARSAC zero-redundancy sequence" 1100101, which gave the pattern of observing days within a week as well as the pattern of observing weeks [1]. After the six-year hiatus, the CONT campaigns were observed every three years starting with CONT02. All of the campaigns were observed for 15 days with various number of stations.

CONT02 (October 16–31) had eight participating stations with the goals of obtaining scientific analysis of daily and sub-daily tidal models, VLBI technique improvement for atmosphere studies, reference frame repeatability, and comparisons with other geodetic techniques. Water Vapor Radiometer (WVR) data was collected at Kokee, Onsala, and Wettzell.

CONT05 was observed for 15 days beginning September 12 with 11 participating stations. There were several goals for CONT05. Two weeks of continuous high frequency (sub-daily) EOP addressed the discrepancies seen between the tidal and atmospheric models, specifically the observations at the M2 and S1 frequencies and the long-term and short-term values of tidal amplitudes. Continuous data allowed a comparison of the estimates of the troposphere zenith delay and gradients across experiment boundaries as a measure of the accuracy of the observations and analysis. Analysis of reference frame repeatability day to day was made and compared with previous continuous VLBI series. CONT05 was strongly endorsed by the IERS because it was an important source of data for the IERS Combination Pilot Project.

The CONT08 campaign was observed on August 12–27 with two improved characteristics. One significant change for CONT08 from previous CONTs was increasing the recording rate from 256 Mb/s to 512 Mb/s. With 512 Mb/s recording and a network with larger geographical coverage, the sub-daily precision

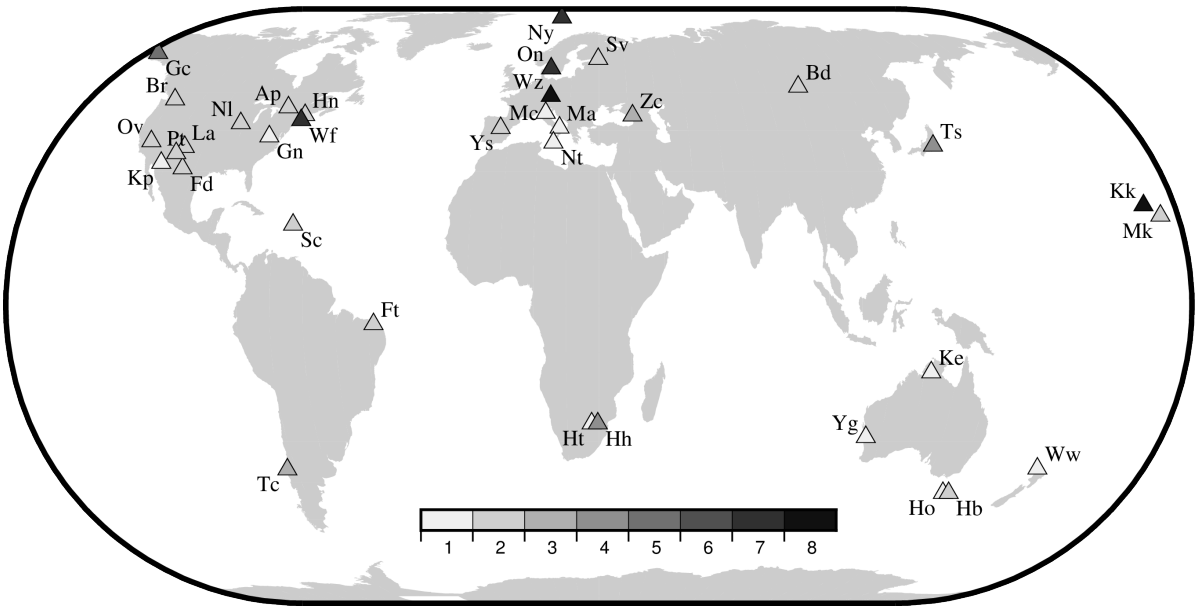

Fig. 1 Thirty-five stations have contributed to CONT campaigns during the last 20 years. The light grey triangles show the stations participating in one to four CONTs, whereas the dark grey triangles display the stations participating in five to eight CONTs.

was expected to be better than earlier CONT campaigns, thus allowing for further testing of theoretical tidal models. First detection of ter-diurnal signals related to M3 and S3 tidal phenomena in the oceans and the atmosphere was achieved with the CONT94, CONT02, and CONT05 data. The anticipated precision of the CONT08 allowed further investigation of these phenomena. The CONT08 network had a larger geographical coverage than previous CONT campaigns and thus promised to be more sensitive to smaller scale features in the ionospheric activity. A combination of VLBI and GPS for the derivation of total electron content (TEC) maps was possible. The CONT08 troposphere delay estimates were also compared with WVR results, GPS estimates, and Numerical Weather Models (NWM).

The large 13-station network of CONT11 (September 15–30) had a reasonably balanced geographical distribution between the northern and southern hemispheres. CONT14, observed during May 6–21, had the largest network of all the previous CONTs—17 stations with reasonably balanced geographical distribution between the northern and southern hemispheres. Both campaigns allowed further studies of high frequency EOP variations, analysis of ocean tide models, tests of theoretical models, and derivation of TEC maps.

3 Resources and Quality

Figure 1 shows how many times a station participated in a CONT campaign. There have been eight CONT campaigns thus far. Two stations, Wettzell and Kokee have participated in all eight campaigns. The global coverage of the CONT campaigns improved with more coverage in the south. HartRAO-26m was added to the CONT campaigns in 2002, but there was a significant improvement in polar motion when both HartRAO-26m and Tigo were included in the CONT05 campaign (see Figure 3).

The CONT campaigns used, and will continue to use, a large amount of resources including station time, recording media, and correlator time. Table 2 displays how much correlator time was used to support the CONT campaigns. This required that all other sessions, except the IVS-R1 and IVS-R4, not be processed until the CONT campaigns were completed. The CONT14 campaign was processed with the DiFX Correlator at Bonn in 38 days. This was a significant improvement from previous CONT campaigns. It shows that we are moving in the right direction with the DiFX correlator so that we will able to process the massive amount of VGOS data that we plan to obtain.

Figure 2 shows the general increase in several measures of the size of the CONT campaigns. The sta-

Table 2 Resources used for the eight CONT campaigns. The IVS was established in 1999 between CONT96 and CONT02.

Campaign	#stations	#sources	Media	Recording rate	Correlator center	Correlation time	Correlator type
CONT94A	7	41	thin tape	112 Mbps	Haystack	n/a	Mark IIIA
CONT94B	7	41	thin tape	48 Mbps	Haystack	n/a	Mark IIIA
CONT95	6	34	thin tape	112 Mbps	Washington	n/a	Mark IIIA
CONT96A	5	40	thin tape	56 Mbps	Haystack/Washington	n/a	Mark IIIA
CONT96B	12	44	thin tape	128 Mbps	VLBA	n/a	Mark IIIA
CONT02	8	50	thin tape	256 Mbps	Bonn/Haystack/Washington	58/89/45 days	Mark IV
CONT05	11	74	Mark 5	256 Mbps	Bonn/Haystack/Washington	50/81/68 days	Mark IV
CONT08	11	80	Mark 5	512 Mbps	Washington	163 days	Mark IV
CONT11	13	117	Mark 5	512 Mbps	Washington	146 days	Mark IV
CONT14	17	73	Mark 5	512 Mbps	Bonn	38 days	DiFX

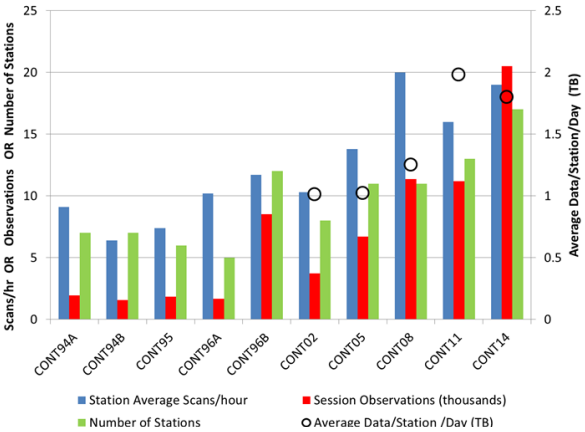

Fig. 2 Size of CONT campaigns: sources, scans, and observations.

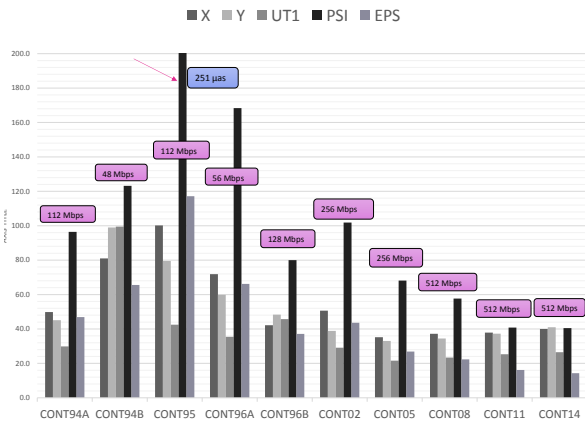

Fig. 3 The EOP formal uncertainties steadily improved after CONT02. This was due to larger networks and increased recording rates.

tion average scans per hour were better in CONT08 than in CONT14, but CONT14 had five more stations than CONT08. That is why the number of session observations in CONT14 was much higher than previous CONTs. The average data per station per day was largest in CONT11. The average data per station went down slightly in CONT14, which may be due to the larger network, which allows more subnetting during the scheduling of the stations. The formal errors did not improve significantly for X, Y, or UT1 when the recording rate was increased from 256 Mb/s to 512 Mb/s in CONT08, but it did improve for PSI and EPS.

4 Future CONTs

We are in the planning stage of CONT17. The Coordinating Center and the Observing Program Committee (OPC) began discussions about CONT17 in early 2016. There were discussions regarding simultaneous networks, media, and correlator(s). CONT20 has not been discussed yet (see Table 1).

The plan is to have the next CONT campaigns in late 2017. We want to have as many VGOS stations as possible observing simultaneously with the legacy stations. As mentioned earlier, a vast amount of resources will be needed to support this campaign. Currently only the Haystack correlator can process the VGOS data; so, we need at least two correlators to process the data: one to correlate the VGOS data and the other to process the legacy data. Due to limited correlator resources, the huge amount of data from a dual network cannot be processed by one correlator. Mark 6 modules need to be purchased to support the VGOS observing. Depending on the recording rate, additional Mark 5 modules may need to be purchased as well. There have been additional discussions about including the VLBA in the

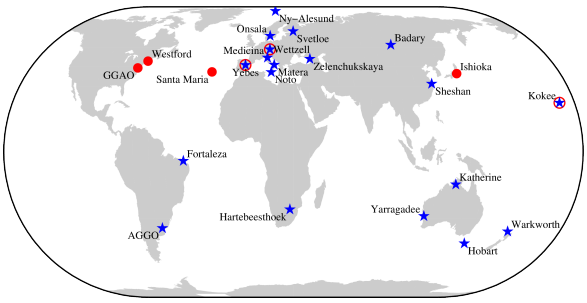

Fig. 4 Possible CONT17 networks with legacy stations (stars) and VGOS stations (circles) observing simultaneously.

CONT17 campaign. The strategy of this campaign is still being coordinated by the OPC.

We are also considering having a pre-VGOS Observing Campaign for CONT20. This would be 15 days of VGOS-only observing to determine if the stations and the correlators can handle continuous VGOS observing. This will test the bandwidth for e-transfers along with module shipments. This also means that each station will have to be able to record continuously while sending their large volumes of data to the designated correlator(s).

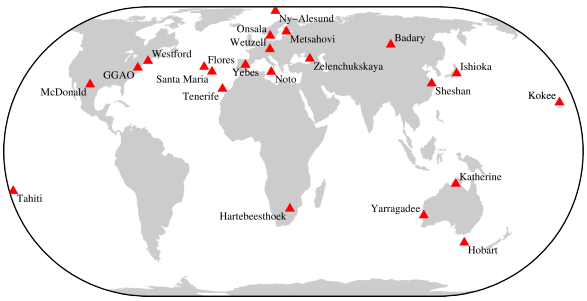

Fig. 5 CONT20 with VGOS stations observing only. The goal is to employ as many VGOS stations as possible by 2020.

5 Conclusions

We have come a long way in regards to the number of stations, data rate, media, and processing time of the CONT campaigns. We have gone from as small as a five station network to a 17-station network. We are planning for larger networks in the future. The recording rate has increased from 56 Mb/s to 512 Mb/s, which has decreased the formal errors significantly, as seen in Figure 3. The media changed over the years from thin tape to modules and sending the data via e-transfer. The e-transferring of data will present complications in the future if the bandwidths are not upgraded to support the large amount of data being produced. We have seen a major improvement in getting the CONT14 data processed with the DiFX correlator. The DiFX correlator will help with processing the VGOS data in future CONT campaigns.

References

1. Thomas A. Clark, Chopo Ma, James W. Ryan, Benjamin F. Chao, John M. Gipson, Daniel S. MacMillan, Nancy R. Vandenberg, Thomas M. Eubanks, and Arthur Niell, 1998, “Earth Rotation Measurement Yields Valuable Information About the Dynamics of the Earth System”. In EOS, Transactions, American Geophysical Union, Volume 79, Number 17, pp. 205–216.